NISTIR 6527

Measurement Needs for Fire Safety: Proceedings of an International Workshop

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U.S. Department of Commerce
William M. Daley, Secretary

Technology Administration
Dr. Cheryl L. Shavers, Under Secretary of Commerce for Technology

National Institute of Standards and Technology
Raymond G. Kammer, Director

ZONE MODEL

- I/O and required Measurements for Model Validation

FORUM WORKSHOP
at NIST
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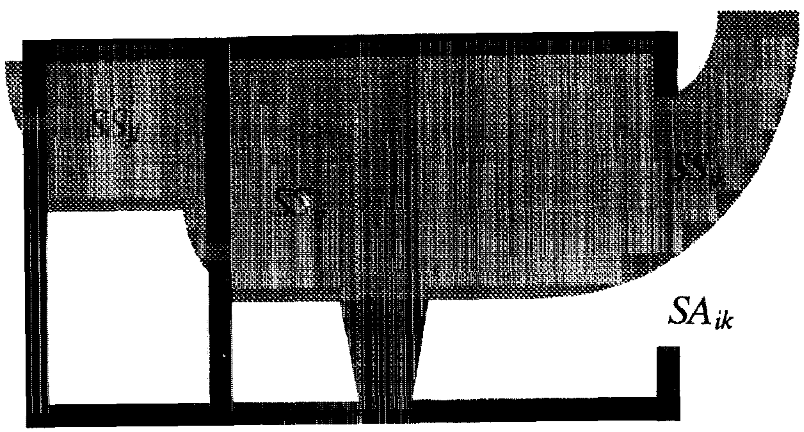
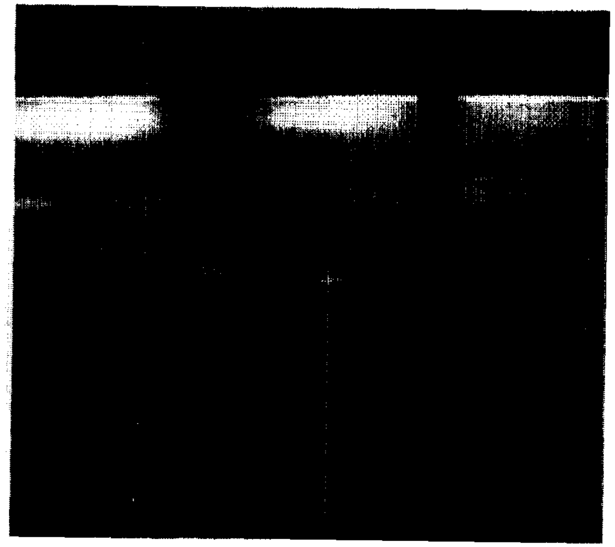
What is Zone Model ?

- Fire phenomena characterized by small numbers of zone, which are of uniform temperature and yields of product species (usually 2 zones)
- A set of physical models to reconstruct macroscopic fire phenomena



What is essential for fires being predicted by Zone Model ?



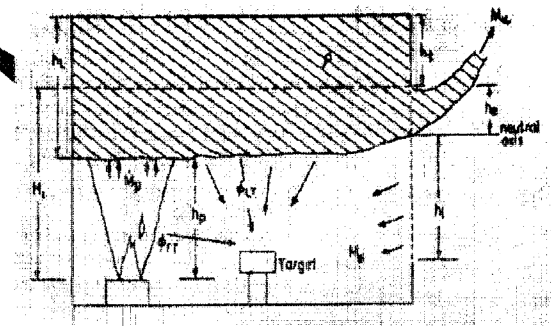
- *For predicting with good accuracy*

  The target phenomena in fires are expected to be characterized by well-mixed and/or layered

Zone model developed (example)

USA

- Harvard Computer Fire Code, FIRST
- CFAST, CCFM, FAST
- ACOS(network), ASET, FPETOOL



JAPAN

- BRI2(T), SMKFLOW(net work model)
- various kind of Code developed by Construction Company (based on BRI2)

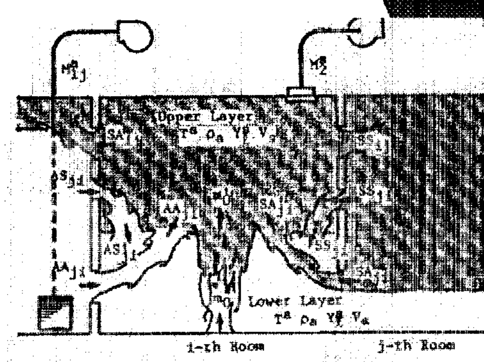


Fig.1 Conceptual model of the fire in a multiroom geometry

AUSTRALIA

- FIRECALC

What are Zone models used for and by whom ?

Very Popular

- Building Fire Safety Deign by enginee[illegible] designers
  - A. Smoke filling model for large space[illegible]tadium)
  - B. Smoke control design (especially pressurizatio[illegible]

Inexperienced (in Japan)

- Reconstruction of real fires by attorneys or investigators for court, administrative issues
- Education and Fire Fighters Training by Instructors

A. Smoke Filing model for large space

●**Design Policy**

Use large volume as a smoke reservoir and extend egress available time.

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Smoke Filing model for large space

- **Important information required by zone model**

Life safety point of view

1) When will the smoke layer fall down to [illegible]pe level ?

If it falls down earlier than egress completion, then

2) How large vent is necessary to keep the clear [illegible] for evacuation and fire brigade operation ?

3) How hot or contaminated is the smoke layer ?

Building Property damage prevention

4) Can the glass roof in the atrium break by the exposure to the smoke layer?
5) Can the column collapse by the compartment fire?

• Input Data and Its data range, accuracy required

1. Initial Conditions

(a) Building Configulation

Rooms (Width, Depth, Height)

magnitude: $10 \sim 10^2$ m in order

- **Horizontal Section Area on =*f* (Heig**

  in real situation : measurable accuracy i 1m (2%)

Opening (Size : Width, Height(top, bottom))

(Location: Orientation, Connection between room

magnitude: $1 \sim 10^2$ m in order

- Flow coefficient α should be specified.(0.7 to 0.85)

  The accuracy is almost 5% or little less.

(b) Ambient Temperatures: Inside and outside of the building.

- **Vertical temperature profile =T (Height)**

spatial resolution corresponds to the steepness of temperature,

temporal : a couple of minutes is enough.

- **Input Data and Its data range, accuracy required**

2. Boundary Condition

(a) Thermal Property of Surroundings of large space (Time independent)

κ (Thermal conductivity), ρ (density), c(specific heat) of materials of large area, i.e. ceiling.

- Adequate convective heat transfer α is more important.

(b) Fire Heat Source (Time dependent)

Model fire for design.

Heat release rate: ranging from 3 to 25 MW

Fire Area :0.5 m^2 to 17 m^2

Real Fire: (*discuss in burning Item models in detail)*

Generaly adopt pool fire of methanol.

Heat release rate: estimated by total mass devided by bur time duration. Accuracy is less than 5% empirically.

- Fire area data give much effect on Plume volume.

● Input Data and Its data range, accuracy required

2. Boundary Conditions

(c) Outdoor Conditions of Winds :. *Not well discussed and considered*

Average wind velocity and coefficient of winds pressure are estimated by using reference velocity measurement at the roof top.

Design level : Statistic of the meteorological is utilized.

Most frequent direction and intensity of winds are refe

Experiment Level: Temporal resolution is 1sec. to 1 min. and 10 to 20 min averaged data are used.

Measuring point is only one base point and various spatia data are estimated as input data for ventilation.

(d) Mechanical Ventilations:

Design level : Only specific exhaust rates are defined.

Experiment Level : *Just trust product specification*

For large space, Indoor static pressure is supposed to be ambient .

So mechanical property of "pressure – volume" dose not give much effects on exhaust rate.

Output & Exp. Data required for Model Validation (1)
- Smoke Layer Information (1/2) -

- **Layer Height and the Time Curve**

1)Prediction

Temporal resolution : less than 5 sec. (1 s ideal)
(for evaluating egre)
Spatial resolution : less than 0.5 m in som ight.
(interface of smoke laye us)

- **The required resolution seems to be time & space-dep**
In early stage, smoke layer falls down rapidly, so fine res
preferable for both temporal and spatial features.

2) Measurements required for model validation
Temperature profile (N% method)
Temperature rise, smoke meter , observation

Output & Exp. Data required for Model Validation (2)
- Smoke Layer Information (2/2) -

- **Average Temperature**

  1)Prediction

  Temporal resolution : less than [illegible] sec. (1 sec is ideal)

  Accuracy of Temperature : less than 5 [illegible] for evacuation
  less than 20 [illegible] property)

  2) Measurements required for model validation

  Temporal : (same as prediction)

  Spatial : At least 3 thermocouple trees in vertical [illegible]
  each of them having more than 10 vertic[illegible]

- **Combustion Products**

  Temporal resolution : less than 5 sec. cm

  Spatial resolution : one or two base point inside smoke laye[illegible]
  (usually the gas yield is well mixed and unifo[illegible]

• Output & Exp. Data required for Model Validation (3)

- Inlet and Exhaust related Data -

• Statistic Pressure Difference between in/out-door

1) Prediction

Temporal resolution : less than 10 sec.

Accuracy : less than 0. 05 pa

(which gives 0.3m/sec velocity res

2) Measurements required for model validation

Spatial : one base point at the bottom of floor level

(measurement at the top of the space is preferab

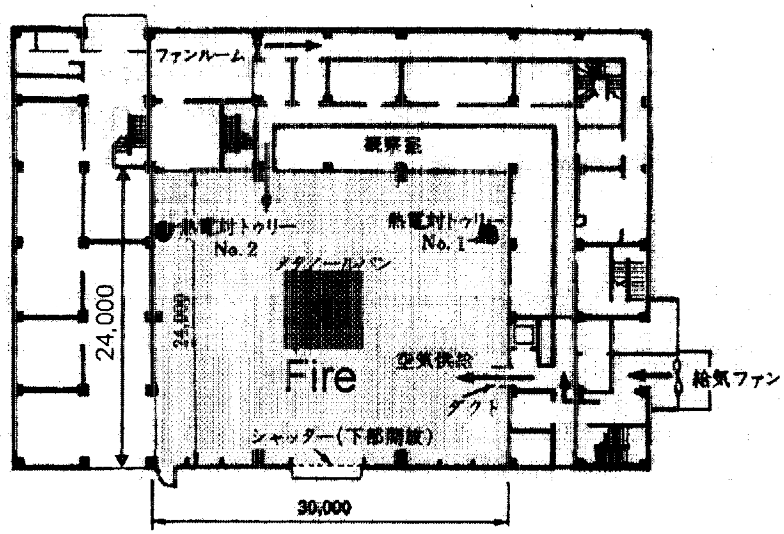
Temporal : less than 10 sec.

* *usually for Smoke filling validation, pressure data are not major*

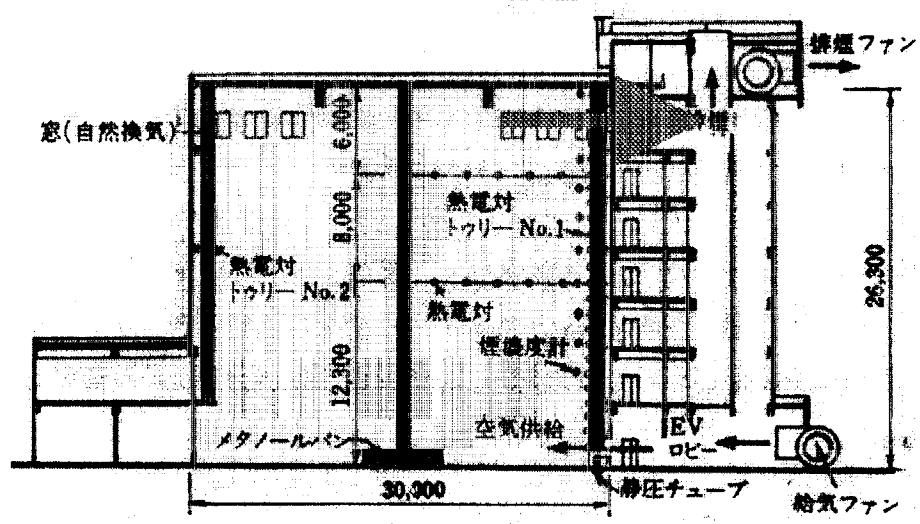
● EXAMPLE of Experiment for Model Validation

- BRI Exp. -

Experimental Setting : Heat Input 1.3 MW



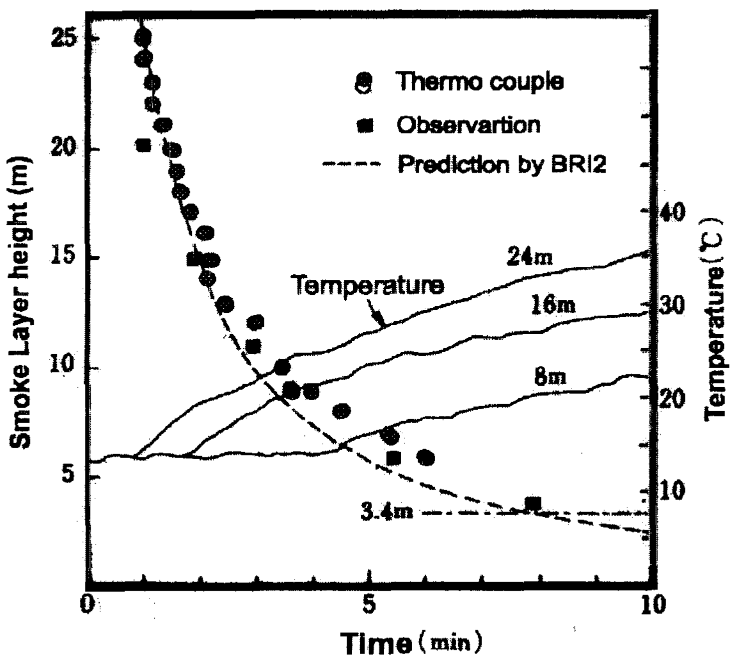
PLAN



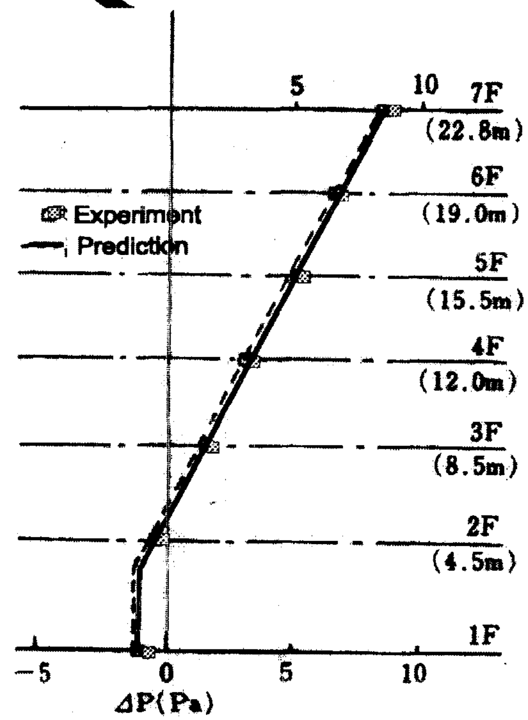
ELEVATION

● EXAMPLE of Experiment for Model Validation

- BRI Exp. -



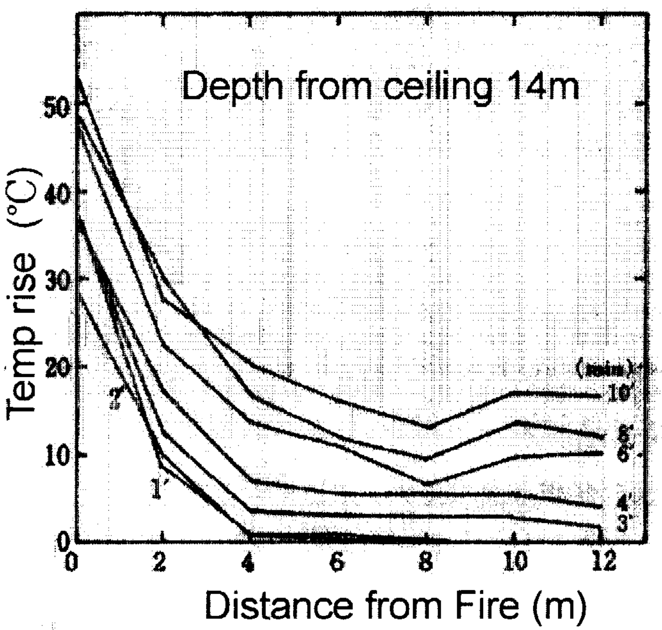
Smoke Layer Drop & Temperature rise
(Mechanical Vent : 6 m³/sec)

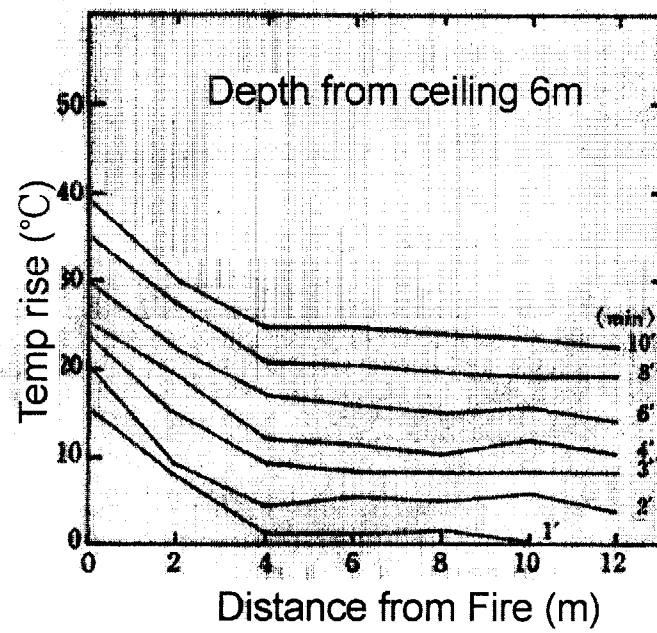


Statistic Pressure Difference between in & outside

- **EXAMPLE of Experiment for Model Validation**

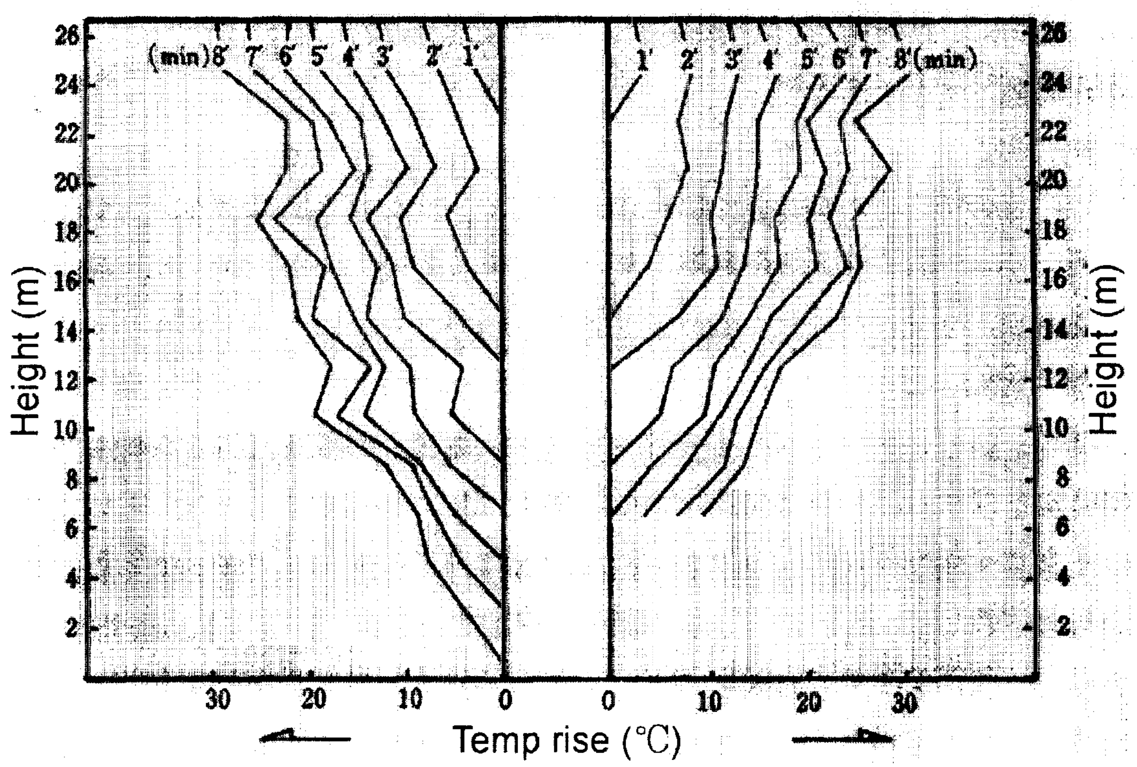
- BRI Exp. -





- **EXAMPLE of Experiment for Model Validation**

- BRI Exp. -

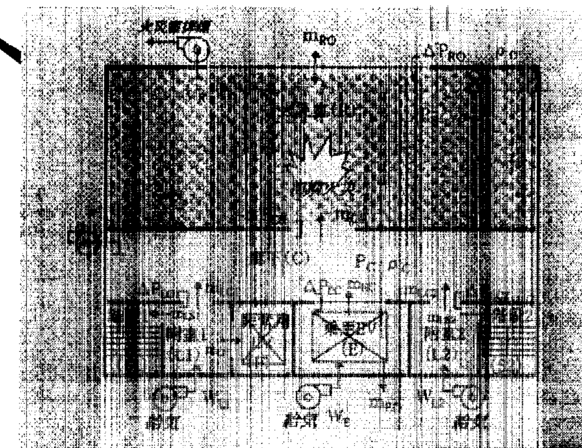


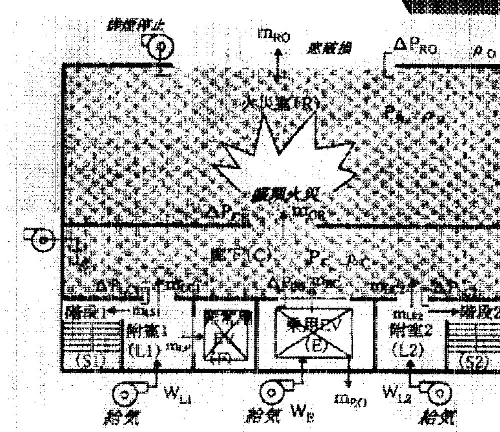
B. Smoke control design (pressurization)

- **Design Policy**

1) Stop Smoke between fire room and corridor at the stage of floor evacuation

2) Stop smoke between corridor and vestibule, and elevator shaft and corridor at the stage of fire brigade operation and total evacuation





• Important information required by zone model

Life safety point of view

1) Prevent smoke flow out through opening to escape route for evacuees, and access route (including vestibule and stairwell) for fire fighters

2) Release excessive pressure rise to avoid door [illegible] /closing issues for evacuees.

For these purpose the information needed is

- How much air supply rate is necessary to protect esc route?
- How much vent openings are needed for obtaining moderate and adequate pressure differences between spaces ?

● Input Data and Its data range, accuracy required

1. Initial Conditions

(a) Building Configulation

Rooms (Width, Depth, Height, Floor level heig

magnitude: 1 ~ 100 m in order

in real situation : measurable accuracy is 0.1 - m

- **Special concerns be paid for stairwells and ele shaft etc.**

Opening (Size : Width, Height(top, bottom))

(Location: Orientation, Connection between rooms)

magnitude: 1 ~ 10^2 m in order

Flow coefficient α should be specified.(0.6 to 0.85)

The accuracy is almost 5% or little less.

- **Apertures** (Size : Effective area α A, Height(top, bottom))

(Location: Orientation, Connection between rooms)

The accuracy highly depends on buildings' qua

Smoke control design (pressurization)

- **Example of Effective area αA of Apertures**

Aperture of Building Part	Flow Coefficient		
	by unit area (Óá A/A)	by unit length (áA/L)	default
External Wall	0.08×10^{-3} - 1.6×10^{-3}		0.0016
Floor	0.02×10^{-3} - 1.7×10^{-3}		-
Stairshaft enclosure	0.01×10^{-3} - 0.2×10^{-3}		-
Elevater shaft	0.11×10^{-3} - 0.96×10^{-3}		-
Doors for egress (opened)	0.6 - 0.7		0.7
Door in stairwell (one door type)	(0.005 - 0.012)	0.0017 - 0.0040	-
Door in stairwell (two door tipe)	(0.003 - 0.005)	0.0015 - 0.0022	-
Door inside buildings	(0.004 - 0.007)	0.0013 - 0.0024	0.01
Elevater front door	(0.008 - 0.014)	0.0034 - 0.0051	0.014
Shutter for smoke area	0.0005		-
Shutter for fire area	0.0055		-
Fire damper	0.013		-
Inside stairwell	0.17 - 0.23		-

cf. L: total length of boundary

● Input Data and Its data range, accuracy required

1. Initial Conditions *(continued)*

(b) Ambient Temperatures: Inside and outside of the building.

Vertical temperature profile =T (Height) … only considered for shafts and outdoors.

Spatial resolution : one temperature for each ro

temporal : a couple of minutes is enough.

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2. Boundary Condition

(a) Thermal Property of Surroundings of ~~large space~~ rooms (Time indep

κ (Thermal conductivity), ρ (density), c(specific heat) of materials of large area, i.e. ceiling and wall surface.

Adequate convective heat transfer α is more important.

- Heat loss to walls is rather small compared with ventilation heat movement.

Input Data and Its data range, accuracy required

2. Boundary Condition

(b) Fire Heat Source (Time dependent)

Model fire for design.

Heat release rate: ranging from 3 MW to [illegible] level

Fire Area :0.5 m^2 to ~~17~~ m^2 compartment floor area

Recently T-square fire is getting familiar

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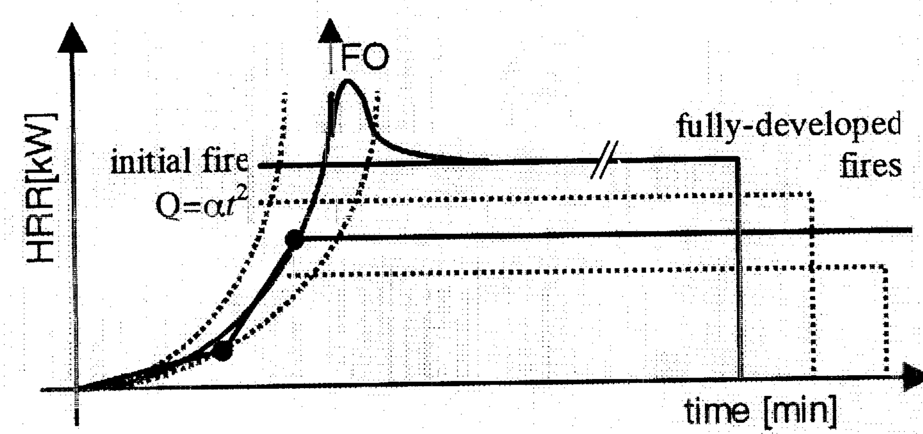
Real Fire:

(same as smoke filling case)



Input Data and Its data range, accuracy required

2. Boundary Condition

(c) Outdoor Conditions of Winds :. *Not well discussed and considered*

Average wind velocity and coefficient of winds pressure are estimated by using reference velocity measurement at the roof top.

Design level : Statistic of the meteorological is utilized.

Most frequent direction and intensity of winds are

Experiment Level: Temporal resolution is 1sec. to 1 min. and

10 to 20 min averaged data are used.

Measuring point is only one base point and various sp

data are estimated as input data for ventilation.

(d) Mechanical Ventilations:

Design level : Supply air and Exhausts smoke flow rate =V (ti

Set Opening condition in accordance of of egress schedu

Experiment Level : *Mechanical property of "pressure – volume curve*

taken into account

• Output & Exp. Data required for Model Validation (1)
- Smoke Layer Information (1/2) -

• Layer Height and the Time Curve

1) Prediction

Temporal resolution : less than 5 sec. (1 s[illegible] preferable)
(for evaluating egre[illegible]e.)

Spatial resolution : less than 0.2 m .
(interface of smoke laye[illegible]us)

The leyer height is not so important.

- One layer zone model (net work model) is more popular for this case)

2) Measurements required for model validation

Temperature profile (N% method)

- Mainly temperature profile is measured at door openings.

● Output & Exp. Data required for Model Validation (2)
- Smoke Layer Information (2/2) -

● Average Temperature

1)Prediction

Temporal resolution : less than 5 se (1 sec is ideal)
Accuracy of Temperature : less than 5 ℃ vacuation

2) Measurements required for model validatio

Temporal : (same as prediction)
Spatial : At least 1 thermocouple trees in vertical,
each of them having more than 5 vertical p

● Combustion Products

Temporal resolution : less than 5 sec. cm
Spatial resolution : one base point inside smoke layer.

● Output & Exp. Data required for Model Validation (3)
- Inlet and Exhaust related Data (1/2) –

● Statistic Pressure Difference between in/out-door

1) Prediction

Temporal resolution : less than 5 sec.
Accuracy : less than 0. 01 pa
(which gives 0.13m/sec velocity re

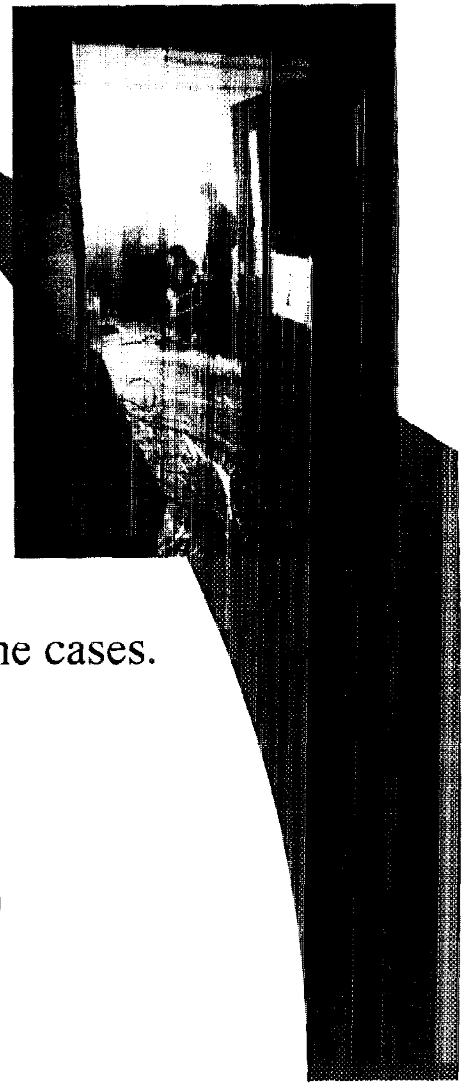
2) Measurements required for model validation

Spatial : one base point at the bottom of floor level for e
at least 3 points in the stairwells
Temporal : less than 5 sec.(1 sec is preferable)

~~Velocity at the opening and vent.~~
~~tatistic Pressure Difference between in/out-doo~~

● Output & Exp. Data required for Model Validation (4)

- Inlet and Exhaust related Data (2/2) –



● Velocity at the opening and vent.

1) Prediction

Temporal resolution : less than 5 sec.

Accuracy : less than +-0. 10 m/sec.

2) Measurements required for model validation

Spatial : 5 vertical points at each of door openings.
1 at Supply and Exhaust Vent by anemometer or pitot tube.

Temporal : less than 5 sec.(1 sec is preferable)

Simple Measurements by using woolen yarn is applied in some cases.

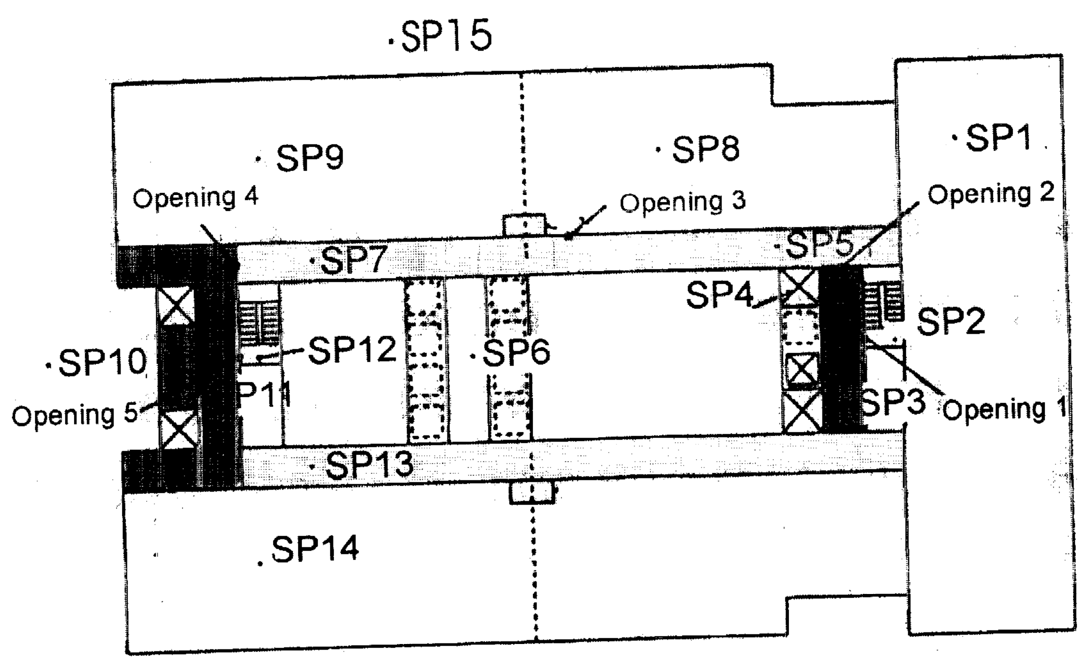
● Total Door Opneing/Closing Force.

prediction & Measurements

Temporal resolution : (during pressurization period)

Accuracy : 0. 005*door area N

- **EXAMPLE of Experiment for Model Validation**
  - High-rise Building Pressurization Exp. -

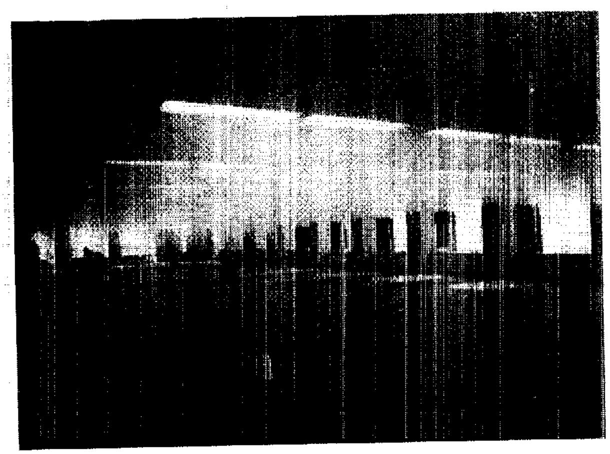


- **EXAMPLE of Experiment for Model Validation**

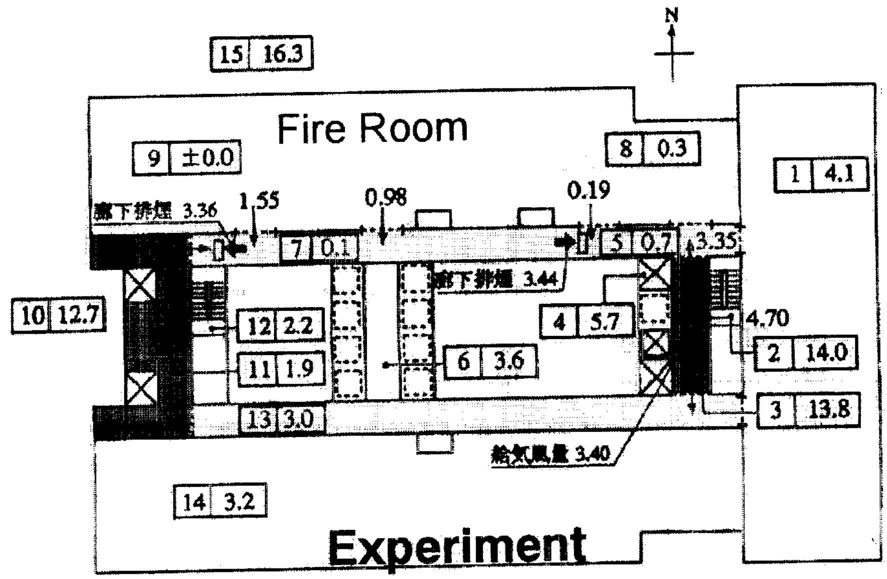
  - High-rise Building Pressurization Exp. -

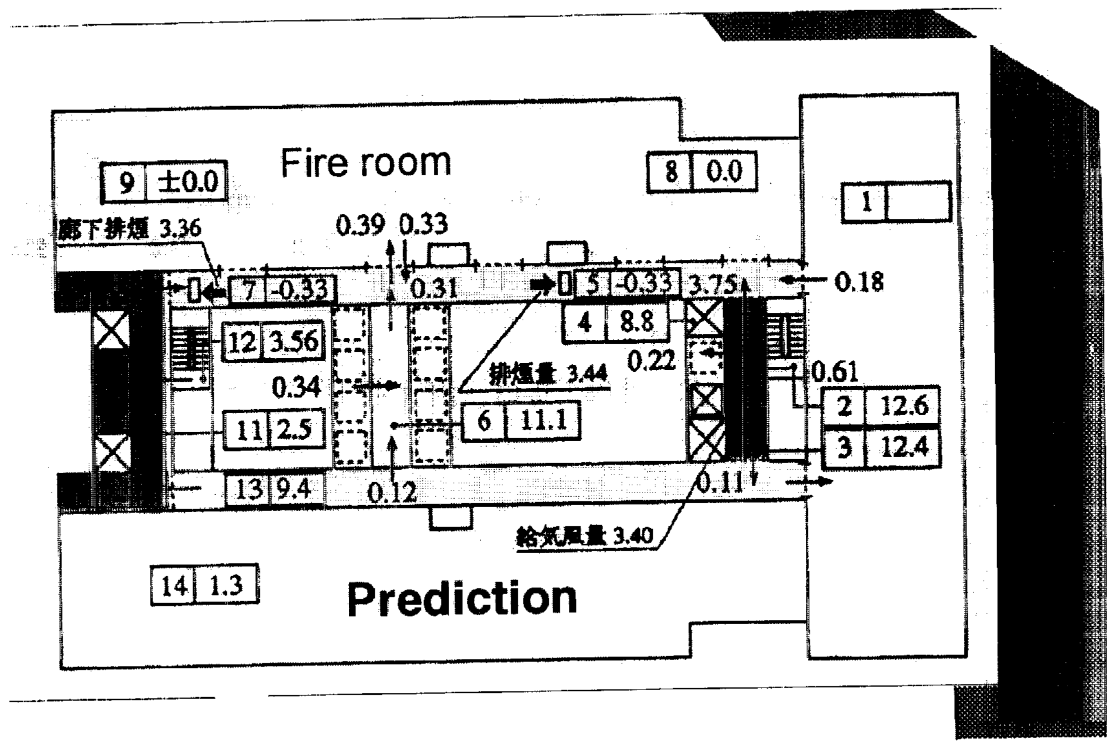
  → Unit: (kg/sec)

  ▭ Unit: (Pa)



Smoke control design (pressurization)





Concluding remarks

FIRE MODELS BELONG MORE TO ENGINEERING THAN TO SCIENCE

- Most of the science findings existed we insufficient to develop a fire model.
- Modeling works need considerable engineerin treatments.
- Fire modeling identified needed area of fire science
- Fire Models will Finds the Ample room for Development in Practical Applications.

(by Dr. Tanaka BRI2 developper:
Professor Emmons Memorial Symposium 2000, March)